Chapter 3

PUBLIC AND PRIVATE FINANCING OF BUSINESS R&D

Introduction

Considerable evidence indicates that business strategies for research and development (R&D) have evolved significantly in recent years. Not only did industry funding for R&D rise in many OECD countries in the 1990s, but the ways in which firms organise, manage and conduct R&D also appear to have changed. The numbers of R&D alliances, mergers and acquisitions and patent licences increased markedly, as did the share of R&D conducted by small and medium-sized enterprises (SMEs) and business funding for university research. These data suggest that firms are moving towards a more open system of innovation, supplementing their strategically oriented internal R&D with technology acquired from a variety of external sources in the public and private sectors.

Such changes have potentially far-reaching implications for science and technology (S&T) policy. To be most effective, government policies to stimulate business R&D and innovation must address the challenges that firms face for financing and conducting R&D[1] and the obstacles that limit knowledge creation, diffusion and exploitation in national innovation systems.[2] Changes in patterns of business R&D may imply compensatory changes in government policy as the rationale for certain forms of government support may have weakened while that for others has strengthened. Indeed, rising levels of business R&D and venture capital in some countries have already raised questions about the levels of government R&D funding that are needed to stimulate industrial innovation. Countries that have seen slower growth in business R&D are actively seeking policy measures that can efficiently boost private-sector R&D spending while taking emerging business practices into account.

This chapter aims to inform the policy debate by examining fundamental changes in the financing, organisation and conduct of business R&D and their implications for S&T policy. It presents key statistics describing private and public financing of business R&D and reviews the major changes in business strategies for R&D from the perspective of the firm. It then identifies important issues that policy makers will need to address to enhance not only the effectiveness of public financing of R&D but also the performance of national innovation systems. These include greater emphasis on knowledge creation, SMEs and intellectual property rights (IPRs). While the general conclusions are broadly applicable across the OECD area, the steps that individual countries take will need to be tailored to the characteristics of local industry (specific industries, their relative stage of development) and the capabilities of other elements of their national innovation systems.

Changing patterns of business R&D investment

At the aggregate level, available statistics indicate growing business investments in R&D, as well as the emergence of a more diversified business R&D system in many OECD countries. Business R&D performance is not limited to large manufacturing firms, but is found in a wider range of large and small firms in both manufacturing and services. As a result, governments will need to find ways to better support a more heterogeneous mix of R&D-performing organisations and to ensure necessary linkages among them. They will also have to find ways to avoid crowding out the growing R&D expenditures of a more diverse set of private-sector institutions.

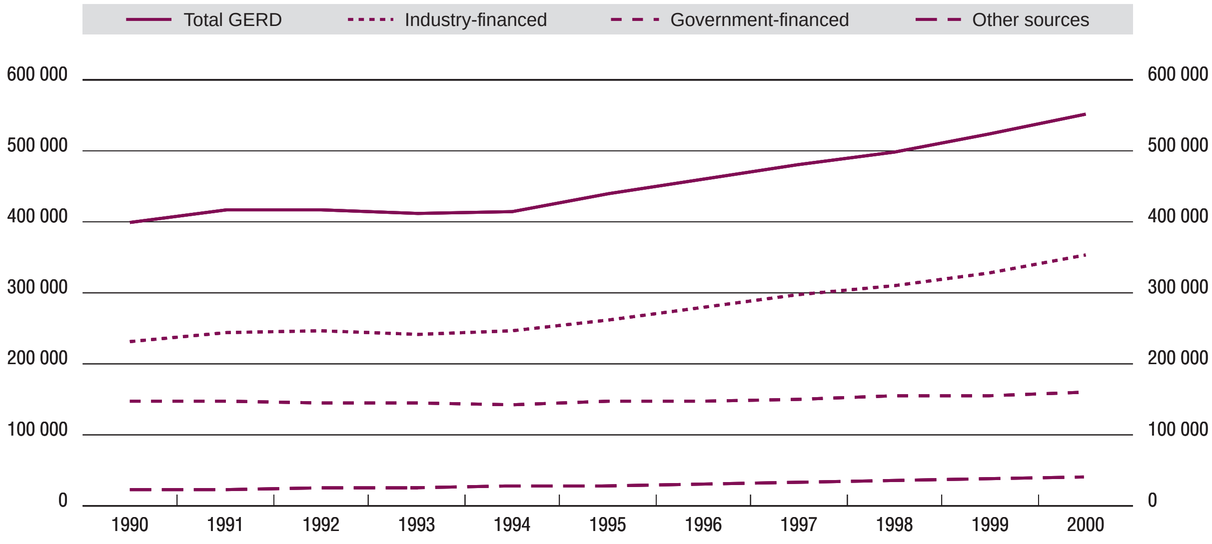
Business R&D investments grew in the OECD *area*

Aggregate statistics show that business R&D fared well in the OECD region in the last decade, with both industry financing of R&D and industry performance of R&D posting gains. Between 1990 and 2000, industry funding of R&D rose 53% in real terms, from approximately USD 230 billion to more than USD 350 billion (Figure 3.1). Total business enterprise expenditures on R&D (BERD) – a measure of R&D performed in the business sector – grew by 39% in real terms during this period, from USD 276 billion to USD 385 billion.[3] In both cases, most of the growth occurred after 1994, following a period of stagnation at the beginning of the decade. Between 1994 and 2000 – a period of relatively rapid economic expansion – growth in industrial R&D outpaced growth in the economy as a whole, with industry-financed R&D increasing from 1.23% to 1.43% of gross domestic product (GDP), and BERD growing from 1.40% to 1.56% of GDP in the OECD region.

Business R&D grew rapidly despite stagnant government spending on R&D throughout the 1990s. Direct government funding of R&D grew by 8.4% in real terms between 1990 and 2000, from USD 147 billion to USD 159 billion.[4] As a result, government represents a declining share of R&D financing in most OECD countries. Government funding for R&D declined from 37% of total OECD funding for R&D to less than 30% in the 1990s, continuing a trend that stretches back at least to 1981. Industry financing accounted for 64% of gross national expenditures on R&D (GERD) in the OECD area in 2000, up from 58% in 1990.[5] While these trends are most pronounced in the United States, they are mirrored to a lesser degree throughout the OECD area.

The changing balance between publicly and privately financed R&D implies that business interests and concerns will have greater influence over R&D agendas and spending in the future. While this change links R&D efforts more closely to market needs, it also makes R&D more sensitive to business cycles. Industry-financed R&D climbed during the last half of the 1990s when company profits and growth prospects were strong, but it is uncertain how company R&D budgets will fare during economic downturns when corporate revenues and profits stagnate. Many firms reaffirmed their commitment to R&D in 2001 by boosting R&D budgets despite gloomy economic forecasts (Boslet, 2001), but an

Figure 3.1. **Gross expenditures on R&D in the OECD region, 1990-2000**
Millions of constant 1995 PPP dollars



Source: OECD, *Main Science and Technology Indicators*, June 2002.

extended downturn could eventually undermine R&D spending by industry. Furthermore, the increased linking of R&D to business and market needs may influence the types of R&D that firms support, a topic to be discussed below.

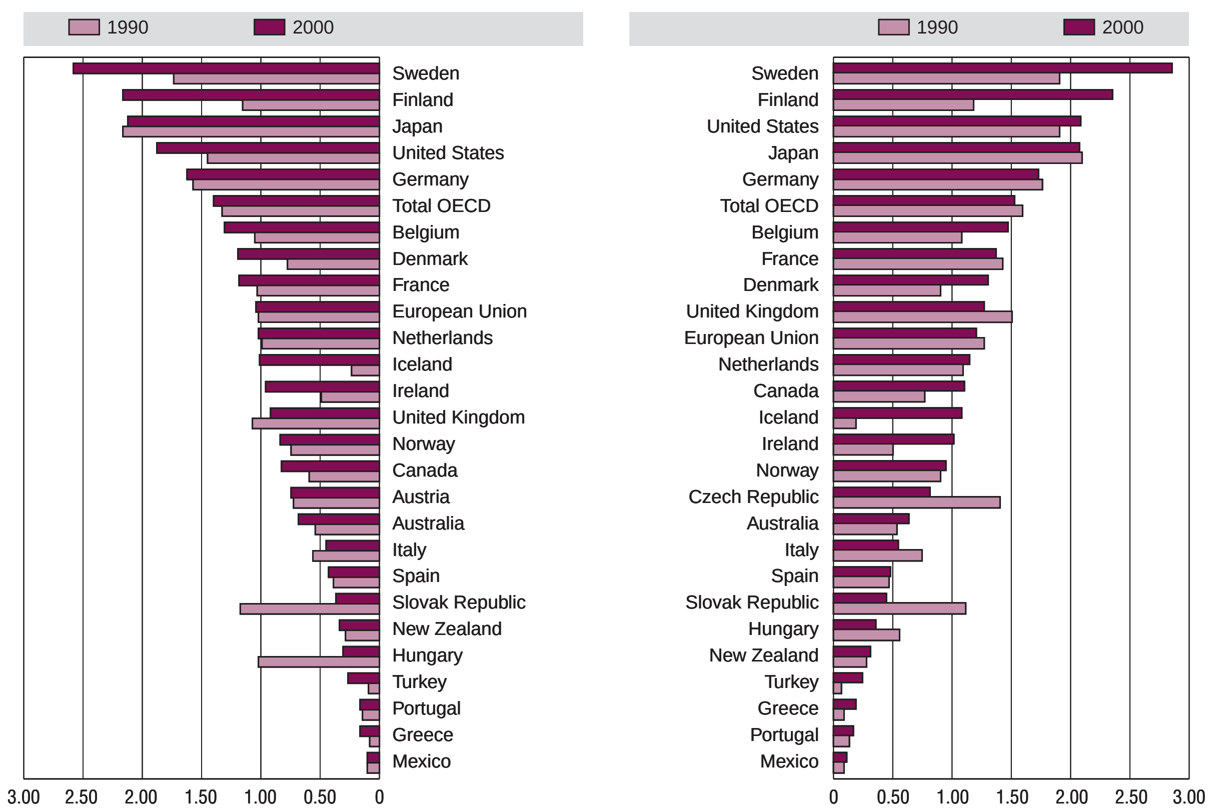
Growth in business R&D was uneven

OECD-wide statistics mask significant variations in levels and patterns of R&D growth across OECD regions and countries. In the European Union, industry R&D spending averaged just 1% of GDP in 1999, a figure virtually unchanged from 1990 and considerably below that of other OECD countries, such as Japan, Sweden and the United States (Figure 3.2). Firms in the European Union also lagged companies in Japan, the United States and the Nordic countries in R&D performance. A recent survey of the largest R&D-performing firms in the three regions produced consistent results, showing a higher R&D intensity for US firms (7.4% of sales) than for those headquartered in Japan (5.3%) or Europe (4.7%) (Reger, 2001).

Moreover, during the 1990s, increases in the intensity of industry-financed and business-performed R&D were limited primarily to smaller OECD economies and the United States. Finland, Sweden, Iceland and Ireland saw increases in BERD intensity of more than half a percentage point during the decade, driven largely by increased industry funding, but with growing financing from government and foreign sources as well (Figure 3.3). The United States also saw large increases, despite significant reductions in government financing. In several other large OECD economies, including Italy, Japan and

Figure 3.2. **National trends in industry-financed and business-performed R&D relative to GDP, 1990-2000**[1]

Industry-financed R&D as a percentage of GDP | Business-performed R&D as a percentage of GDP

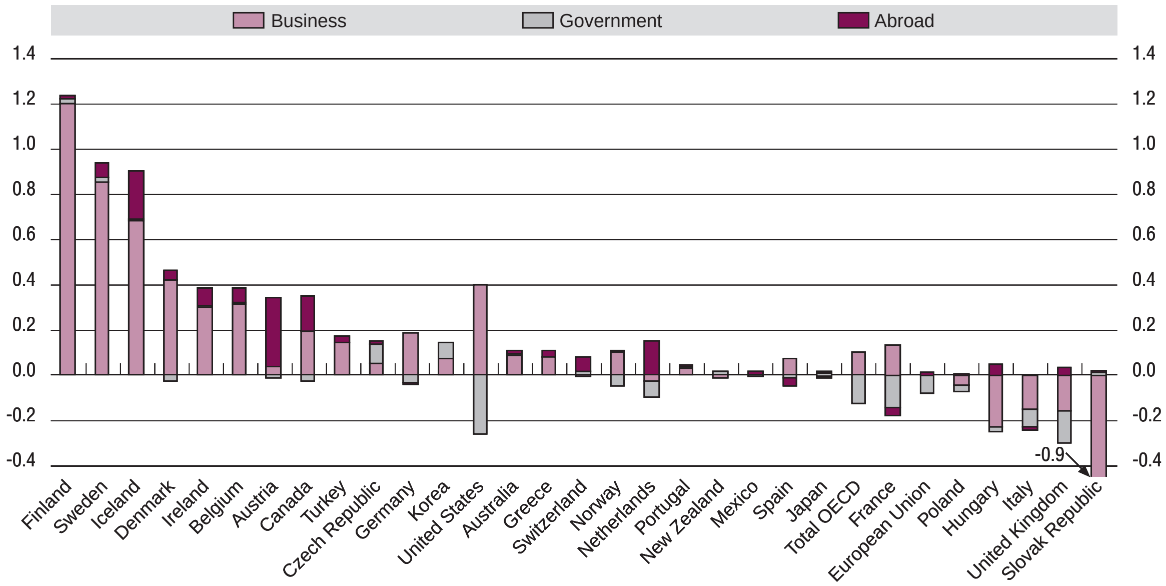


1. Nearest available year.

Source: OECD, MSTI database, June 2002.

Figure 3.3. **Change in BERD intensity by source of funds, 1990-2000**[1]

Percentage point change as a share of GDP



1. Nearest available years.
Source: OECD, MSTI database, June 2002.

the United Kingdom, industry financing and business performance of R&D declined in real terms and as a share of GDP. All but Japan saw significant reductions in BERD financed by industry and by government, the drop in the latter largely the result of steep cutbacks in defence-related R&D. Over the decade, government financing declined from over 14% of BERD in the European Union to less than 9%. In many large European countries, these trends have renewed interest in identifying ways to boost flagging business R&D expenditures, while limiting the impact on government expenditures. This has included examination of mechanisms such as new or expanded tax incentives for business R&D investments, promotion of venture capital markets and ways of stimulating R&D investments by private, non-profit organisations (such as private foundations).

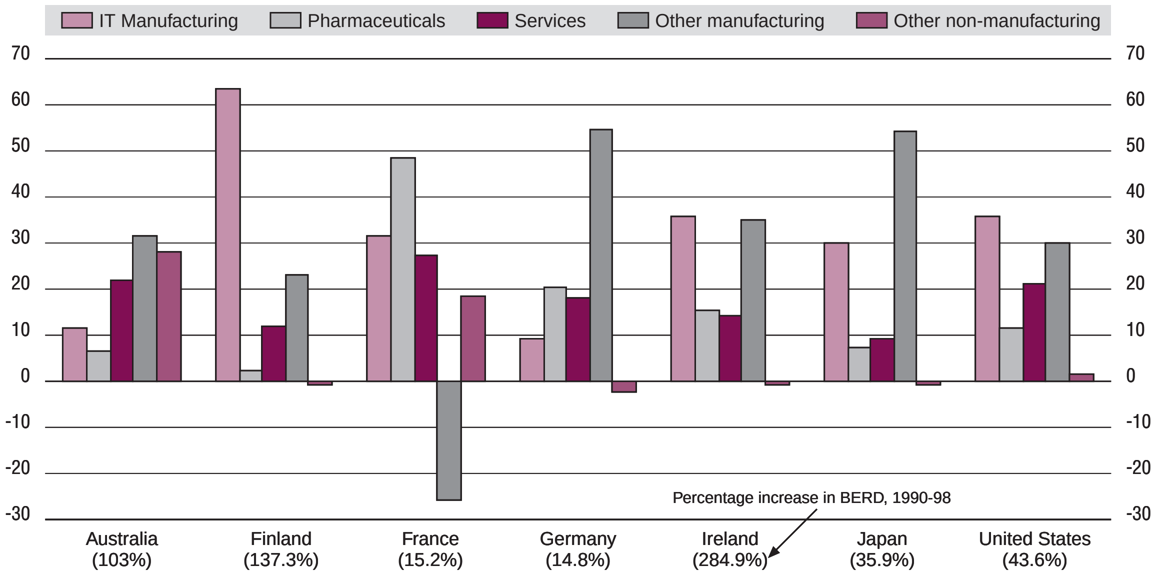
High-technology manufacturing and services drive R&D growth

High-technology industries, such as ICT and pharmaceuticals, and the services sector account for a disproportionate share of business R&D (Figure 3.4). In Finland, where total BERD more than doubled between 1990 and 1998, approximately three-quarters of the increase came from these sectors and 60% from ICT alone. Similarly, in the United States, where BERD increased by 44% during this period, more than 70% of the growth came from the same sectors.[6] Ireland and the Netherlands saw services sector R&D increase at an average rate of more than 20% a year in the 1990s, with Ireland also seeing strong growth in ICT. The situation contrasts to that of Germany and Japan, where more than 50% of their much more limited growth in BERD came from increases in traditional manufacturing sectors, such as transportation equipment and machinery.[7]

The increase in BERD is consistent with a transition towards more knowledge-based economies. Knowledge – especially scientific and technical knowledge – is increasingly embedded in new products, processes and services, and industry sectors that are intensive users of technology and highly skilled human capital represent a growing share of business sector value added and employment (OECD, 2000b). These sectors include producers of high-technology goods, as well as knowledge-intensive service industries, such as finance, insurance, business, communications and computing

Figure 3.4. **Distribution of the growth in business R&D between 1990 and 1998[1] by industry**

Percentage of total increase in BERD



Note: Information technology manufacturing includes office and computing machines, communications equipment and electronic components. The decline in R&D in other manufacturing industries in France derives from steep reductions in defence expenditures (OST, 2000).

1. Nearest available years.

Source: OECD ANBERD database, June 2002.

services. More traditional industries in both the manufacturing and services sectors are also becoming more knowledge-intensive, as they increasingly apply new technology to their operations and develop and exploit new scientific and technical knowledge that allows them to improve their productivity.

Venture capital contributed to growing business R&D

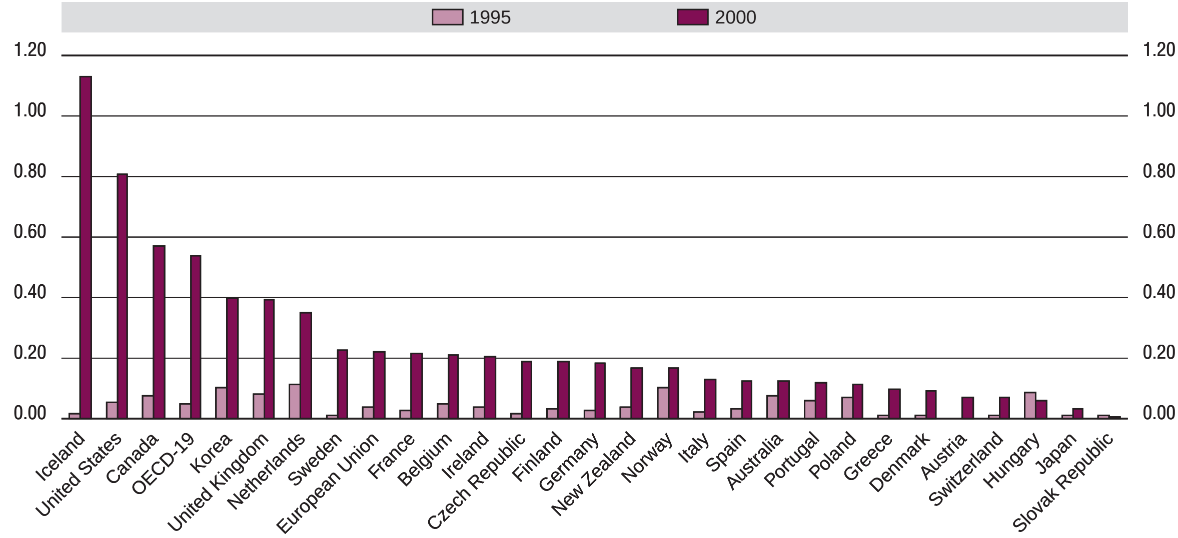
Contributing to the increase in private-sector investment in R&D was the rapid growth of venture capital in many OECD countries. Venture capital does not support R&D directly; rather, it provides financing to risky business ventures. Early- and expansion-stage venture capital, in particular, tends to finance the activities of small, growing companies that are active in high-technology fields. Because these firms also tend to be highly R&D-intensive, early- and expansion-stage venture capital supports a significant level of R&D in small companies. Most of this R&D is oriented towards development rather than research, and is captured in statistics on BERD.

Many OECD countries saw their venture capital markets grow rapidly between 1995 and 2000. The United States has the most developed venture capital sector in the OECD area, with more than USD 100 billion invested in 5 380 companies in 2000,[8] although Canada, the Netherlands and the United Kingdom also had levels of early- and expansion-stage venture capital above 0.3% of GDP in 2000 (Figure 3.5). Such funds tend to be highly skewed towards high-technology sectors. In Canada and the United States, more than 60% of these funds were directed to the ICT and health/biotechnology sectors *versus* approximately 30% in the European Union and Japan.

The economic downturn that began in 2001 resulted in a significant decrease in venture capital funding and its redirection towards expansion funding for established companies (Richtel, 2001). Nevertheless, levels of venture capital financing are expected to remain high compared to levels of just a few years earlier, and some countries have been relatively less affected. US venture capital funding

Figure 3.5. **Growth of venture capital markets in OECD countries, 1995-2000**

Early- and expansion-stage financing as a percentage of GDP



Note: Data for Czech Republic, Hungary, and Poland are for 1998-2000. Data for Slovak Republic are for 1999-2000.
Source: OECD, based on various sources.

declined steeply in 2001, from USD 106 billion to USD 41 billion, as the economy weakened and market valuations of technology companies fell. However, new investments in 2001 were almost twice as high as in 1998. European venture capital also declined significantly between 2000 and 2001, from a high of EUR 19.6 billion to EUR 12.2 billion, but investments still exceeded their 1999 level.[9] In Canada, venture capital investments declined less dramatically, from USD 6.3 billion to USD 4.9 billion, although biotechnology investments increased from USD 666 million to USD 842 million.

Increased venture capital funding appears to have helped spur increases in the share of business R&D conducted by SMEs in some countries. Firms with fewer than 500 employees accounted for less than 20% of business R&D in Germany, Italy, Korea, Sweden and the United States in 1997 (OECD, 1999). In the United States, however, R&D expenditures of SMEs increased at almost twice the rate of those of large firms between 1990 and 2000, with R&D expenditures of the smallest firms increasing most quickly (Table 3.1). As a result, their share of total industry R&D expenditures grew from 12% to almost 20% between 1990 and 1999 before declining to 18% in 2000 (National Science Foundation, 2002).

This trend reflects not only the availability of venture capital funding, but also a significant reduction in the scale and scope of activity needed to develop successfully a number of emerging technologies, especially in the areas of ICT and biotechnology. The decreasing costs of experimentation in some fields enables universities to explore technical concepts and products to a degree not previously possible, especially in science-based industries such as ICT and biotechnology (Pavitt, 2000). A new division of labour may therefore be possible in the innovation process, one that places SMEs in the position of mediating the relationship between knowledge generation in universities (and to a lesser extent, in public laboratories) and the exploitation of knowledge by large firms.

Small technology-based firms (*e.g.* high-technology start-ups) play an important role in innovation, especially in high-technology industries. They are often more effective than large ones at commercialising radical innovations that open new product markets because: *i)* they can satisfy their

Table 3.1. **R&D expenditures by US SMEs**
Millions of constant 1995 USD

No. of employees	1997	1998	1999	2000	% change
Fewer than 25	2 730	4 088	5 986	5 435	99%
25 to 49	2 642	2 713	4 103	4 379	66%
50 to 99	3 676	5 540	6 201	6 171	68%
100 to 249	6 358	7 117	6 124	7 640	20%
250 to 499	5 628	5 934	6 935	6 239	11%
Total SME	21 034	25 393	29 349	29 846	42%
SME share	16.4%	18.4%	19.6%	18.1%	

Source: National Science Foundation (2002).

need for revenue growth by concentrating on markets that are initially small; *ii*) they tend not to have an installed base of customers that discount the value of new technology (which is often inferior in some important dimensions to existing technologies);[10] and *iii*) they do not have to worry about cannibalising existing product lines (Christenson, 1997).[11] Nevertheless, the R&D programmes of new technology-based firms are smaller and more targeted than those of large, R&D-intensive firms. High-technology start-ups may therefore serve more to complement than to compete with the broader, long-term R&D portfolios of some larger high-technology firms. Large firms are attempting to develop more efficient ways of leveraging the R&D of small firms and of learning from the experimentation that occurs within them.

Restructuring business R&D

As important as the overall changes in patterns of business R&D has been the restructuring of R&D processes within firms themselves, a change which is especially noticeable in the organisation of R&D within large multinational corporations. Despite the increased role of small start-up firms, large firms continue to wield considerable influence over patterns of innovation. In the late 1990s, large firms (*i.e.* those with more than 500 employees) accounted for 93% of all business R&D in Japan, 81% in the United States, 78% in the European Union and 74% in Nordic countries. They also exert considerable influence over the R&D programmes of firms in their broad supplier networks.

Over the past decade, large firms restructured their R&D operations to improve their linkages to overall strategic objectives and improve the efficiency of their R&D investments. The effects of these changes were perhaps most pronounced in centralised corporate research labs, which perform most basic research in the business sector, but whose research results are often very difficult for parent firms to appropriate. There are many examples of technologies being brought to market by competitors that did not conduct the R&D,[12] and such experiences have motivated firms to increase the link between R&D and innovation.

From closed to open innovation processes

Throughout the 1980s, leading industrial R&D laboratories tended to be closed, in that research investigations were launched within corporate research laboratories, evaluated and screened internally and then selectively transferred to development divisions. Product divisions incorporated the results of R&D into new products and services that were sold through internal channels of distribution.

This paradigm worked well for most of the 20th century. It led to many technological breakthroughs and fostered a virtuous circle of R&D: breakthroughs in the lab enabled new products, services and features to be brought to market; these offerings boosted the company's sales and profits, which in turn financed new R&D to start the cycle again. The paradigm was based on a linear model of innovation and the assumption that most technologies have strong first-mover advantages, a proposition that is only weakly supported by the evidence and was undermined as the dominant positions of many large firms were challenged by new entrants. Nevertheless, companies felt that the more they spent on internal R&D, the greater would be their future payoffs.

It was assumed that firms could anticipate the important technologies that would be needed for advancing their businesses and that most of the best people in the field worked for their firm. These assumptions led firms to rely extensively on internal R&D rather than external research activities. They led managers to undertake long-term research because they believed their staff could identify the areas where investigations were needed and because they felt that they possessed, or could readily attract, the best and the brightest researchers to carry out the necessary R&D.[13]

The viability of the closed model of industrial innovation has been undermined by a number of changes in the environment in which firms conduct R&D. The increasing mobility of skilled workers, the growing capabilities of university research, the more diffuse distribution of knowledge, the erosion of the dominant market positions of many large firms and the enormous increases in venture capital have compromised the ability of companies to appropriate the returns on their investments. Firms' discoveries are increasingly at risk of diffusing out of the company and bringing them little or no compensation. For example, the growing availability of venture capital makes it easier for skilled researchers to create new companies that make use of knowledge gained in research conducted at other firms. While many such spin-offs fail, those that survive contribute new products and services to the economy which often compete with those of the parent firm. Not only does the firm that conducted the original research fail to capture the returns on its investments, hence breaking the virtuous circle, but the spin-off firm is generally less likely than the parent firm to invest heavily in basic research for the next cycle of innovation.

One illustration of the effect of the broken circle is Xerox Corporation's experience in the 1980s and 1990s. While the company did succeed in creating many technologies that improved its copiers, it created other technologies that were more valuable in other businesses, such as computers and networking. Xerox intentionally spun off 30 companies from its research between 1979 and 1998. While many of these companies failed, ten were either sold at a large profit or became public companies themselves. As of June 2000, the market value of these firms was over USD 40 billion, compared to less than USD 15 billion for Xerox. Hence, while a great deal of value was created, little of that value accrued to Xerox (Chesbrough, 2002b).

The problem is by no means unique to Xerox. During the period 1980-97, semiconductor manufacturers (with the notable exceptions of IBM and AT&T) conducted relatively little basic research (as measured by publications in academic journals). They relied instead on third parties, such as university researchers, public research or research consortia, to conduct the research necessary for advances in their industry. The relative lack of participation in scientific research does not appear to have hindered their ability to invent. While IBM leads the industry in patents (and made major investments in basic research, as evidenced by scientific publications), other leading patenters (*e.g.* Motorola, Toshiba, Texas Instruments, Mitsubishi) produced a small fraction of the scientific articles produced by IBM researchers. The commitment of IBM and AT&T to basic research appears to have created a wealth of public scientific knowledge, an intellectual commons, which other firms were able to exploit.

Other factors continue to exert considerable influence over firms' R&D strategies:

- *Shorter time to market.* In many industries, increased competition is forcing firms to shorten the time to market for new products and services. Attempts to speed up the innovation process have altered business R&D processes. For example, the need to introduce new products and services rapidly into the marketplace has forced some firms to assemble component technologies developed by other companies rather than develop the component technologies themselves. This shifts their R&D towards the development end of the spectrum, leaving others to conduct the underlying research.
- *Expanding technological competencies.* In industries ranging from aircraft to biotechnology to telecommunications, the range of scientific and technological knowledge incorporated into new products and processes is so broad that individual firms cannot maintain all the competencies

required to innovate. Hence, they look to external sources of knowledge and technologies. Firms finance university-based R&D both to address near-term problems encountered in their product and service development efforts and to expand the external pool of knowledge from which they and others can draw.

- *Globalisation.* The global restructuring of business also influences innovation patterns by deepening the specialisation of individual firms and regions and strengthening their interdependence. Firms now look to their foreign affiliates and to foreign firms for new technologies, often deploying them in foreign markets before launching them in their home market.

- *Widespread adoption of ICTs.* The expanding use of information technology and communications networks within the business sector has enabled firms to speed up innovation processes and share information more widely among affiliated firms, suppliers and customers.

The combined effect has been to force firms to restructure their R&D activities. Although the details of this shift are still unclear, the process appears to have taken three major forms. First, firms have reorganised internal R&D operations to increase their contributions to strategic business needs. Second, firms have redoubled efforts to capitalise on technologies developed outside the firm. Third, they have instituted programmes to generate increased tangible benefits from technologies generated inside the firm which cannot be fully utilised internally. These processes have all been implemented in an environment of greater globalisation of R&D. While this evolution is most notable in more highly developed economies, they affect a large share of the business R&D that occurs in the OECD area and may presage changes in other countries as well.

Linking business R&D to business strategy

Mounting evidence indicates that business strategy increasingly drives business R&D investments. Firms actively seek to demonstrate financial returns on their R&D investments and more and more choose to pursue R&D projects that are closely linked to the development of new products, processes and services. A recent survey of large R&D-conducting firms in the United States and Europe showed a significant rise in R&D linked to the development of new businesses and reduced interest in long-term basic research (Industrial Research Institute, 2000) In fact, several corporate research laboratories that were unaffiliated or only loosely linked to a parent firm have been closed or spun off as separate entities.[14]

More often, firms seek to give corporate researchers more incentive to contribute to corporate objectives. They give researchers in centralised corporate research labs that perform much basic research the freedom to explore new scientific and technological opportunities with uncertain outcomes while obliging the labs to contribute to profitability. Several large companies, including AT&T, IBM and Siemens in the ICT sector, downsized or reoriented their corporate laboratories in the early 1990s to align them more closely with product development divisions and company priorities (Buderi, 1999; Computer Science and Telecommunications Board, 2000). Elements of the restructuring include (Chesbrough, 2001b; Coombs, 2001):

- *New funding models.* Funding of internal research laboratories relies less on central funding and more on mixed models in which researchers receive some financial support from product divisions. This requires them to find potential customers for their research results and to develop research agendas that take product divisions' needs into account.

- *Links to the market.* More explicit links are established between research programmes and market needs, whether by researchers working more closely with customers or through more elaborate research planning processes.

- *Reorganisation of staff.* Organisational structures based on traditional academic disciplines are being replaced by problem- or product-oriented structures. Incentive plans are rewarding researchers and research managers for both quality research and contributions to business performance.

Acquiring external technology

A significant aspect of the restructuring of business R&D has been a conscious attempt on the part of many firms to improve the integration of their R&D systems with external sources of technology. This can increase the flow of ideas through the company, making researchers aware of external developments of interest to the firm and speeding the innovation processes.

Externalisation can take many forms, including the outsourcing of basic research to R&D service organisations and partnerships with universities and national laboratories to develop technology (Chesbrough, 2001a). Several countries report increases in the R&D expenditures of firms that perform R&D services and in the amount of industrial R&D contracted to outside organisations.[15] The share of industry R&D funding used to finance research conducted in universities, although still small, more than doubled in the OECD area between 1981 and 2000, driven mostly by gains in the European Union and the United States (Table 3.2). Microsoft Corp., for example, reportedly spent 20% of its growing research budget on university research in 2001 (a share equal to approximately USD 75 million) even as it expanded its internal research capabilities. There is also considerable interaction between industry and public research organisations (*i.e.* universities, government labs) in the form of joint research programmes and licences for public research results, which may not involve significant transfers of R&D funds.[16] While firms often rely on universities and government research labs to assist in near-term problem-solving, they also seek to gain scientific and technological knowledge that can be more broadly applied (Box 3.1).

Smaller firms are also playing a greater role in the knowledge acquisition activities of large firms. While large firms finance some R&D in small firms and license or purchase the results of such work, they increasingly use other mechanisms, such as corporate venture capital (CVC) funds and mergers and acquisitions (M&As), to finance and appropriate the results of R&D conducted in small firms:

- *Corporate venture capital.* CVC funds allow large firms to invest in start-up firms to gain a window on new technologies, stimulate development of complementary technologies or encourage broader use of the investor's technology by establishing a *de facto* standard (Cohen, 2000; Chesbrough, 2002d). The number of companies worldwide with CVC programmes jumped from 49 in 1996 to approximately 350 in 2000 (Figure 3.6).[17] Total CVC investments in the United States climbed to USD 9.5 billion in 1999, or more than 15% of total venture capital spending in the United States (Corporate Executive Board, 2000).[18] Such investments were undoubtedly scaled back or even eliminated after the economic downturn that began in 2001, but they are likely to remain a feature of R&D in certain industries. Intel Corp., which operates one of the largest CVC funds, significantly reduced its investments in 2001, but maintained investments in over 500 firms.[19]

- *Mergers and acquisitions* (M&As). M&As allow large firms to appropriate technology developed in small firms, even if they did not finance the R&D. While firms engage in M&As for many other

Table 3.2. **Industry financing of R&D by recipient of funds**

Percentage of total industry R&D financing

Country/region	To industry			To higher education			To government			To public non-profit		
	1980[1]	1990	2000[2]	1980[1]	1990	2000[2]	1980[1]	1990	2000[2]	1980[1]	1990	2000[2]
European Union	97.3	96.5	95.2	0.7	2.0	2.4	1.5	1.4	2.1	0.5	0.2	0.3
Japan	96.4	95.5	95.7	0.4	0.6	0.5	0.2	0.6	0.1	3.0	3.4	3.7
United States	98.5	98.1	98.1	0.9	1.4	1.3	0	0	0	0.6	0.5	0.6
OECD	97.4	96.7	96.4	0.8	1.4	1.7	0.6	0.6	0.8	1.2	1.2	1.1

1. 1981 for the European Union and total OECD.
2. 1999 for the European Union and total OECD.
Source: OECD MSTI database, April 2002.

Box 3.1. **R&D at Intel**

Intel's R&D strategy highlights the viability of a strategy in which firms rely extensively on external research to complement an active development programme. The approach is suited to firms operating in a regime of rapid technology diffusion. Although it invests heavily in R&D (more than USD 4 billion in 2000, or 12% of sales), Intel eschews large internal research programmes. Its researchers have not been significant contributors to scientific journals, nor have they been awarded many patents (especially considering Intel's size in semiconductors). The experience of Intel's founders (Gordon Moore, Robert Noyce, Andrew Grove) showed them the difficulty of transferring research to production and the likelihood of research results diffusing out of the firm. They concluded that they had to make technological advances in a different way.

For many years, they insisted on developing new technologies on the equipment and in the production environment used for making the current products. This incremental approach essentially forfeited the opportunity to create a fundamental breakthrough technology in a laboratory setting. Intel was effective, however, at recombining existing technologies to create new types of products, such as DRAMs (their initial product), EPROMs (which started from an analysis of the causes of defective DRAMs), and microprocessors (which started as a cheaper way to meet the requirements of a third-tier Japanese calculator manufacturer).

As Intel grew and other firms (notably IBM and AT&T) began to withdraw from leading-edge semiconductor research, Intel adjusted its approach to create internal labs that focused on leveraging external research, primarily at universities and at SEMATECH, the consortium of major semiconductor manufacturing companies. By 1996, Intel was spending USD 100 million annually on equipment grants and donations to 15 US universities (it has since expanded the programme to universities overseas). This put Intel in a position to solicit research proposals from leading university scientists and to fund those it considered most promising. Once funded, Intel's internal scientists maintained contact to track progress and determine if and when an academic project was ready to be transferred to internal development within Intel. The decision to transfer often included offers of temporary consulting employment to university faculty and also selective hiring of graduate students involved in the research.

Intel's investments in university research do not simply create an intellectual commons for other firms. For one, its funding does not cover the full cost of the research. The universities provide faculty and graduate students' salaries, benefits and infrastructure, as well as most equipment. For another, Intel actively follows its grants, so that it is among the first to learn of a new breakthrough. And, because its own research staff is involved from the outset, it is likely to transfer successful breakthroughs as fast or faster than anyone else. Indeed, what is interesting about Intel's R&D strategy is that Intel does not need to own the intellectual property in order to profit from it.

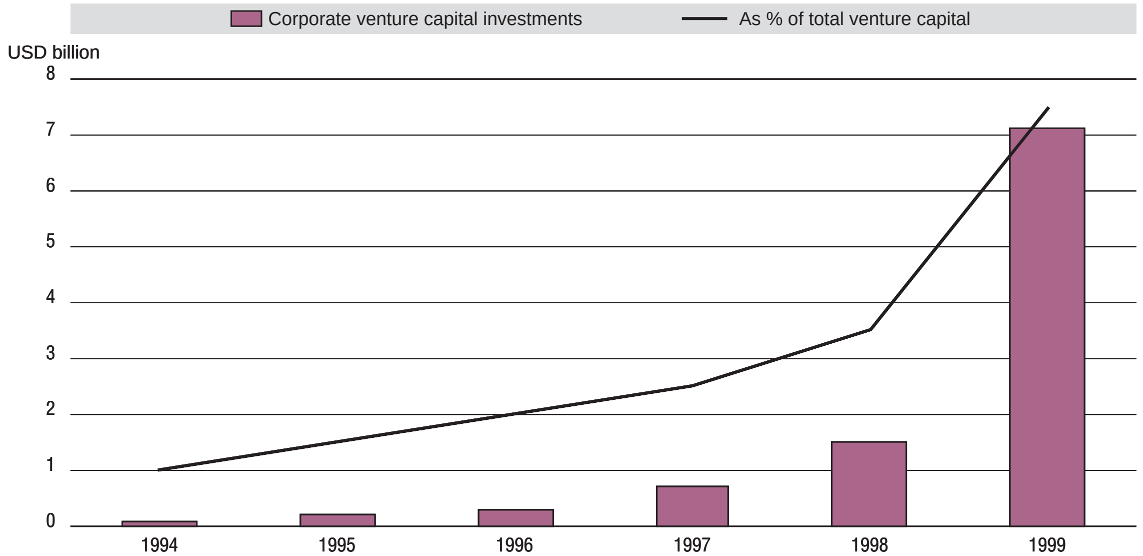
Source: Chesbrough (2002c).

reasons as well, the increasing number of small, R&D-intensive firms acquired by large high-technology firms indicates the growing importance of technology sourcing in such decisions. Firms can choose between developing a technology in house or acquiring it on the open market through a merger or acquisition. Cisco Systems exemplifies the strategy of actively looking for ways to satisfy technological needs through acquisitions. It acquired at least 65 companies between 1995 and 2000 to help expand its product offerings and gain greater capabilities in areas such as optical networking.[20] Such activity is likely to decline significantly as the stock valuations of many high-technology firms decline.

Such practices seem to be most prevalent in high-technology industries, where technological opportunities are numerous and firms must act quickly to benefit from them. In the pharmaceuticals industry, for example, Merck researchers not only generate new internal research but also access external research discoveries in order to create virtual labs in which internal and external research are combined. In addition, Merck launched a CVC fund that invested more than USD 1.5 billion in life

Figure 3.6. **Corporate venture capital investments**

Billions of USD and percentage of total venture capital investments



Source: OECD, based on Corporate Executive Board (2000).

sciences firms in the first half of 2001. It also engaged in M&As valued at USD 27 billion. As a result, externally developed products represent more than a third of Merck's drug sales. Over half of the new chemical entities in active development in the pharmaceutical industry in 2001 are estimated to come from external sources. Such externalisation is also abundantly evident in the ICT sector. At a recent workshop, Alcatel, Intel and Microsoft all reported extensive use of M&As and CVC investments to identify new strategic opportunities, extend the market penetration of standards they have championed, access external technology and transfer new technology into their own operations.[21]

CVC funds and M&As benefit large firms in several ways. By monitoring external R&D efforts, firms can identify in a timely fashion important technologies that are not being developed internally. They can then seek to gain licences for missing technologies for their own businesses or acquire companies that have developed technologies and products of immediate interest to the company. Some firms elect to license their own technology to firms in which they have made CVC investments so that they can be further refined in a different environment. The investing firm may subsequently acquire the other firm or use it as a supplier of a key technology. Still other firms use CVC funds to encourage development of products, technologies or services that complement their own offerings, hoping to boost demand for their own products, technologies or services in the long run.

Rather than weakening (or hollowing out) the R&D capabilities of large firms, external sourcing appears to increase the efficiency of business R&D and innovation systems overall by allowing a wider range of organisations to concentrate their R&D efforts in areas of relative strength. These various forms of inter-firm co-operation allow businesses to nurture and benefit from the development of a wide range of new technologies without committing internal R&D resources to them. They differ from traditional outsourcing of R&D in that they do not typically imply a transfer of R&D to R&D performers outside the firm, with a commensurate decline in internal R&D. Instead, they result more in a change in allocation of internal R&D funding. Companies can dedicate more R&D resources to activities in which managers believe they have the greatest capability, leading to a pattern of deeper specialisation internally and co-specialisation with external sources of R&D. Indeed, recent research indicates that firms that pursue both internal R&D and external sourcing of knowledge have higher rates of innovation, as measured by the introduction of new products and services (Cassiman and Veugelers, 2002).

Of course, patterns differ across industry sectors. Business managers report that innovation aimed at strengthening existing business areas tends to entail greater collaboration with customers, whereas innovation aimed at developing new businesses entails greater collaboration with universities. In markets that are growing more slowly, cost reduction is often a key driver of R&D strategies, and firms participate in joint ventures to pool R&D resources with other firms and share the costs.

Externalising internal technologies

Firms also seek to benefit financially from their own R&D results that do not fit their business plans or match their competencies. They develop ways to leverage and profit from them, *e.g.* through spin-offs and licensing (see Box 3.2). Spin-offs are seen as a means of conducting experiments with technologies that may reveal new technical possibilities and/or new market opportunities. They may subsequently become sources of new technology for the larger firm's current businesses.

Box 3.2. **Externalisation of R&D at IBM**

IBM has historically been deeply vertically integrated. Its approach to R&D in its mainframe computer business was a paradigmatic example of a closed innovation mindset. Today, however, IBM has evolved a rather different R&D strategy. It continues to invest in internal basic research activities, with an estimated 3 000 researchers in labs around the world. However, it now makes aggressive use in its business strategy of external technology developments. This is clearest in its approach to Internet software languages, such as Java and Linux. Both originated outside IBM's labs, yet IBM is a leader in propelling these technologies forward.

IBM has also opened other channels to market for technologies originating in its labs. Its Technology Division is charged with developing advanced technology components. In the semiconductor area, for example, its copper interconnect technology has been widely licensed to most of its competitors in the semiconductor industry. Firm managers calculated that they would gain more revenue by enabling their semiconductor competitors to use the technology than by restricting use to IBM's own products. In aggregate, IBM reported receiving USD 1.7 billion in royalties from its intellectual property in 2000, a year in which it filed 2 886 patents. That figure compares with an investment of approximately USD 600 million in basic research in that year.

In the disk drive industry, IBM sells disk drives to rivals such as EMC. Its Technology Division even sells disk drive heads and media to rival disk drive manufacturers. As a result, its share of disk drive components is greater than its share of disk drives, and its share of disk drives exceeds that of its systems. IBM's position allows it to be the first to develop new head and disk technologies, to be the first to build new production capacity to build these new technologies and to be the most profitable player in the disk drive market, with much of the profits realised in the capital-intensive upstream components business.

At the other end of the value chain, IBM's Global Services division assists the company's clients in making their IT infrastructure work to the client's requirements. This means that IBM will find ways to get anyone's products to work together, regardless of what vendor makes the product. Thus, Global Services makes IBM mainframes tie to Sun servers, to Dell Web servers, to Unix, Windows or even Mac operating systems, Oracle or SAP databases, etc. This has caused IBM to realise that, as capable as it is, no one company can meet all of a large client's IT needs. IBM need not do everything to add value. Instead, it does a great deal in certain parts of the IT value chain internally, but actively partners with external parties in other parts of the chain. In the recent past, IBM's Technology Division and Global Services have been the two fastest growing parts of the company.

Source: Chesbrough (2002c), Chapter 5.

In this perspective, intellectual property (IP) takes on a new aspect. Traditionally, the in-house legal counsel or an external legal advisor managed a company's IP to decide whether and when to patent a technology and how to enforce patents. R&D management was typically involved only to ensure that IP policy ensured open access and design freedom for internal R&D efforts; it cared little about how much money the company might make from its IP. In a more open innovation system, however, firms aggressively market IP that might not be fully utilised internally, and by licensing their technology they gain value.

Globalisation of business R&D

By virtually all measures, industrial R&D has become more global. Existing statistics indicate that the share of R&D financed by foreign sources increased throughout the OECD area in the last decade and now stands at between 3% and 7% in most countries. Japan and Austria represent two ends of the spectrum in terms of globalisation. In Japan, R&D funding from abroad was only 0.4% of total R&D funding in 1995. In Austria, the reported share of funding from abroad increased from 2.6% to 20.1% of GERD between 1993 and 1998, the highest level in the OECD area.[22] These figures do not necessarily include R&D expenditures by foreign affiliates, which may also be large. Almost two-thirds of BERD in Hungary and Ireland was financed by foreign multinationals in 1997, as was one-third of BERD in Canada, Spain and the United Kingdom. Sweden and the United States reported 16% and 12%, respectively.

The motivation for foreign R&D investments appears to be changing, with implications for investment patterns. Traditionally, investments were made in foreign affiliates to allow multinational firms to tailor products to local market needs, often following the globalisation of manufacturing and marketing functions. Increasingly, investments in foreign R&D facilities appear to be motivated by the desire to tap into centres of scientific and technical excellence, a trend that pushes investments towards locations such as Silicon Valley in the United States and Cambridge in the United Kingdom (Sachwald, 2000). Other investments aim at accessing inexpensive labour (as in the software industry) or lower regulatory hurdles (as in the medical devices and pharmaceuticals industries) (Council on Competitiveness, 1998; Council on Foreign Relations, 1998). They also allow large firms to accelerate R&D programmes by having scientists and engineers work on common projects in different locations 24 hours a day.

Firms often find it best to specialise technology research efforts in each regional centre according to the capabilities of that region's human capital. Canon's research centre in Rennes, France, for example, focuses on digital imaging and networks; Microsoft's China lab specialises in speech and character recognition; Siemens Corporate Research Inc. in Princeton, New Jersey (United States), specialises in adaptive information and signal processing, imaging and visualisation, software engineering and multimedia technology. In turn, much of the research output is most valuable in the same region, creating a tighter loop between the discovery of new technology and its initial application. It also informs developments elsewhere in the parent corporation's global networks.

Implications for S&T policy

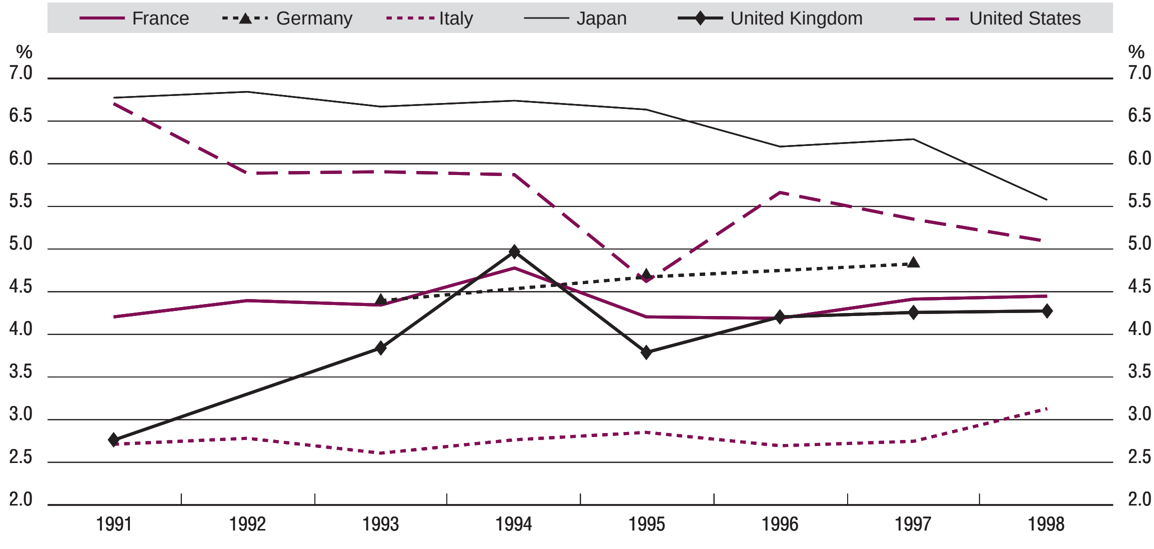
The changes in business R&D raise a number of issues for government S&T policy. Governments have a strong interest in boosting levels of business R&D as a means of improving productivity and economic growth, as well as achieving other social objectives. Just as industry has restructured its R&D activities to make them more effective in the face of a changing competitive environment, governments will also have to adapt their R&D support to the new innovative environment. The question, of course, is how to do this most effectively to attune government support to the more open systems of innovation in the business sector and to avoid crowding out private sector R&D investments. In the area of R&D policy, policy makers will need to address issues such as overall levels of funding, distribution among R&D performers in the business, university and government sectors and instruments for providing funding. They will also have to consider ways to restructure public R&D investments in public laboratories, universities and industry to stimulate business innovation and foster economic growth and ways to ensure adequate linkages among innovating organisations so that knowledge can flow among them and new relationships can be forged (Georghiou, 2002).[23] Governments will also have to reconsider policy in areas such as support to SMEs and entrepreneurship and IPRs, which increasingly affect innovation in the business sector.

Support for basic research

Recent changes in business R&D strategies have arguably helped firms improve the return on their R&D investments, but they have also raised concerns among policy makers regarding their implications for industry support of long-term basic research. This research underpins progress in a growing number of industries, most notably ICT and biotechnology-based industries such as pharmaceuticals, but also in more traditional manufacturing and services sectors. While basic research expenditures have increased in many countries as a percentage of GDP, data on business performance of R&D show that the share of business R&D allocated to basic research fell in the United States and Japan between 1991 and 1998 while increasing modestly in France, Germany, Italy and the United Kingdom, countries where BERD stagnated or declined in the 1990s (Figure 3.7).[24] A number of surveys (*e.g.* Industrial Research Institute, 2000), workshops and interviews with business executives (Chesbrough, 2001a) provide further evidence that businesses in Asia, Europe and North America have cut back on basic research.

Some firms clearly have strong incentives to invest in basic research. The high degree of network externalities in the ICT industry and strong first-mover advantages in pharmaceuticals allow market leaders to reap significant rewards from new products and services, thereby increasing incentives for industry to invest in innovative R&D projects. Nevertheless, the current competitive environment strains firms' R&D resources (in the attempt to get quickly to market), and few firms can afford to finance basic research. Many competitors stand ready to capitalise on advances in science and technology, and the diffusion of research results has become so widespread that companies in many industries struggle to appropriate sufficient return on their research investments. The strength of diffusion mechanisms,

Figure 3.7. **Share of BERD allocated to basic research in selected OECD countries**
Percentage of total BERD



Source: OECD, MSTI database, June 2002.

and the resulting breakdown in the virtuous circle, means that, for the most part, industry can no longer be expected to underwrite most of the costs of early-stage research.

This implies that governments will need to shoulder a growing share of the burden of financing basic research. Firms face the serious challenge of determining how they can best achieve technological advances in their current businesses and how they can establish themselves in new businesses, if they do not undertake significant basic research investments. For government, the challenge is one of maintaining and developing further the knowledge and experimentation necessary to fuel continued innovation. The investments that will create the innovations of 20 years hence will have to be provided in settings other than large firms and will most likely have to be financed by government. Beyond simply financing basic research, governments will also need to ensure that such funding is used effectively. Mechanisms need to be in place to allocate funding to quality research and to evaluate research outcomes.

Improving the mix of mechanisms for financing business R&D

Governments will also need to re-evaluate the mix of policy instruments they use to finance business R&D to recognise the growing diversity of R&D-performing organisations and the need to complement industry's efforts. Direct government financing of business R&D and indirect forms of government support, such as tax incentives, boost privately financed R&D and are often considered substitutes (Guellec and van Pottelsberghe, 1999 and 2000). Nevertheless, the two mechanisms differ in ways that make them more complements than substitutes:

- *Direct financing of* R&D allows governments to target funding towards particular research projects that are believed to offer significant social returns, for example in scientific or technological fields with significant spillovers, basic research or specific government missions (*e.g.* defence, environmental protection, space). Evidence suggests that it encourages firms to take greater risks in their R&D programmes, deepen their research and collaborate with other organisations (Janssens and Suetens, 2001). Direct funding programmes have the disadvantage of relying upon established companies that have the size and resources to work with government, and small firms may be under-represented. They also require governments to administer and manage the financing programme, including the capacity to determine which firms and which fields are to receive funding. This can be especially challenging for governments, especially for programmes that intend to boost economic performance rather than satisfy a more specific public mission.
- *Tax incentives* provide a means of financing a portion of the R&D conducted in all qualifying R&D-performing organisations. This not only enables greater numbers of firms to benefit but also allows individual firms to determine how R&D funds are spent.[25] However, tax incentives do not allow government to direct business R&D easily towards areas with high social returns, nor do they appear to influence corporate R&D strategies significantly (Office of Technology Assessment, 1995). They do not appear to encourage non-R&D performing firms to begin investing in R&D (European Commission, 1999). Rather, tax incentives operate at the level of general budget considerations to expand business R&D programmes. Because they are used against earnings (with some provision for carry-forward), tax incentives are more likely to favour projects that generate near-term profits than long-term exploratory projects and investments in research infrastructure that might generate larger spillovers (David and Hall, 2000).

As a result of these differences, governments rely on a mix of direct and indirect policy instruments to address the specific challenges firms face for financing R&D. Indirect mechanisms, such as tax credits, are used to boost overall levels of business R&D where they are depressed and to extend benefits to a large numbers of firms, including SMEs. More direct forms of support are used to redirect industry R&D efforts towards areas with potentially large social and economic benefits and greater technological risks (and opportunities). The mix of direct financing of business R&D and tax incentives for R&D varies considerably across the OECD area (Table 3.3). In Australia and Canada, for example, the cost to government of R&D tax incentives exceeds direct government funding of business R&D. In countries like France, Japan and the United States, much greater amounts of support are provided to business

Table 3.3. **Direct *versus* indirect financing of business R&D in selected OECD countries**
Millions of 1995 PPP USD

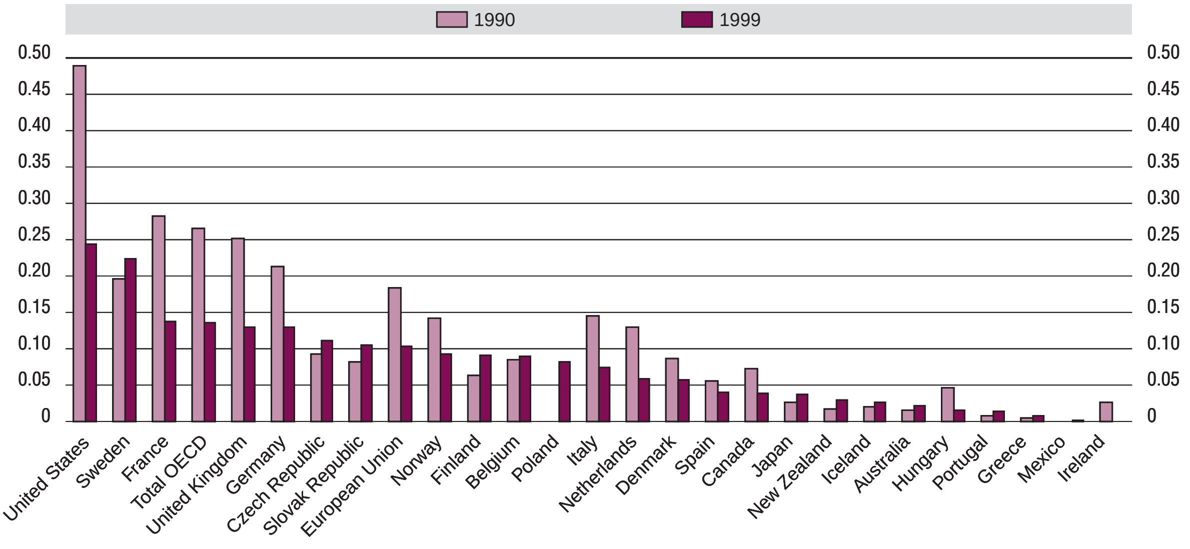
	Cost to government of tax credits	Direct government funding of business R&D	Industry R&D expenditures
Australia (1997)	138	84	3 233
Canada (1995)	685	441	5 143
France (1997)	376	1 778	14 159
Japan (1997)	202	828	65 173
Netherlands (1997)	207	210	3 269
United States (1999)	2 393	23 595	152 617

1. Canadian data do not include the cost of tax incentives offered at the provincial level. US data do not include tax incentives offered at the state level.
Source: OECD R&D database and National Science Board (2000).

R&D through direct financing than through tax incentives. Yet, even in Canada, tax credits are equivalent to only 13% of total industry R&D expenditures; in the United States, they represent less than 1.6% of industry R&D spending.

As innovation diffuses more widely throughout the business sector and new science and technology increasingly drive innovation in high-technology sectors, governments may need to consider a different mix of policy instruments to stimulate business R&D. Direct financing of business R&D has declined in many OECD countries – owing in large part to declining R&D expenditures for defence (Figure 3.8) – and tax incentives for R&D have become increasingly popular. Between 1996 and 2001, the number of OECD countries offering tax incentives for R&D expenditures increased from 12 to 18, and other countries were contemplating new schemes. Direct financing remains an important source of funding for business R&D, especially for encouraging more radical innovation – it continues to exceed 0.2% of GDP in the United States and Sweden, and has increased in many smaller OECD economies[26] – but new mechanisms may be needed to make more effective use of such funds and help channel them

Figure 3.8. **Direct government funding of business R&D, 1990-99**
Percentage of GDP



Source: OECD MSTI database, June 2002.

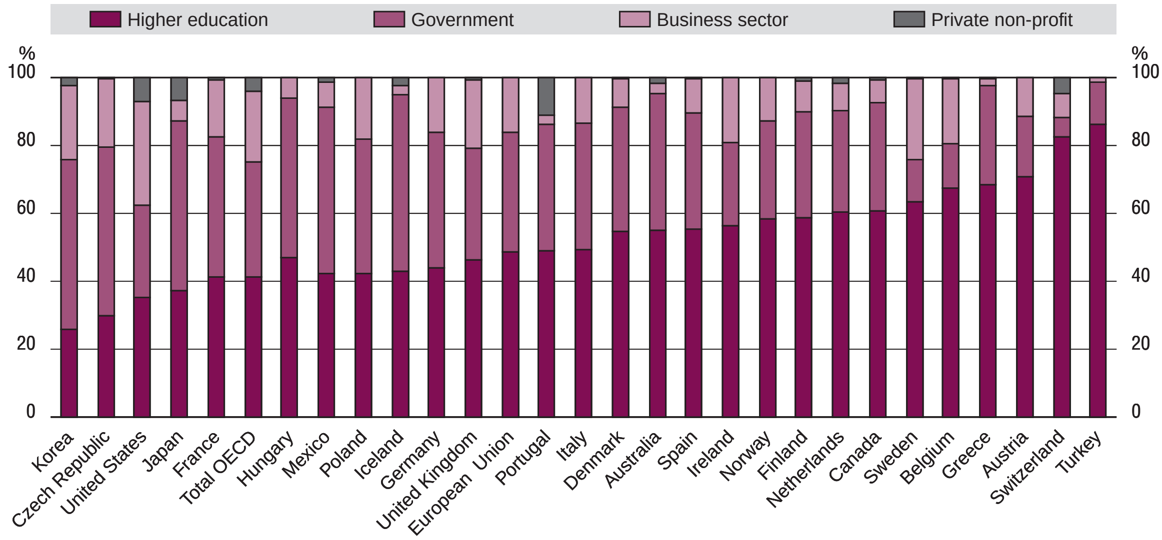
to a more diverse set of industries. In the United States, for example, more than 80% of government funding for business R&D is concentrated in just four industry sectors that are closely related to defence needs: navigational and control instruments, aerospace parts and products, architectural and engineering services, and scientific R&D services. An increasing share of government funding for economic development is now directed to public/private partnerships in the hope of better leveraging government resources and better involving industry in the planning and execution of R&D programmes.

Balancing government R&D investments in industry, universities and government labs

Changing business R&D strategies also imply that governments will need to evaluate support to business R&D more explicitly in the context of financing for public research organisations. Private firms, universities and government labs contribute in different ways to industrial innovation and economic growth; increased private investments in R&D, combined with the emergence of more open models of business innovation, may argue for a different balance of funding across these institutions. For example, the reduction in basic research conducted in firms may imply a need for increased funding for university-based research to ensure the production of skilled S&T workers and new knowledge to stimulate innovation. Historical studies illustrate the important role that government funding of university research played in laying the groundwork for several industries, including biotechnology and the information technology industry (Computer Science and Telecommunications Board, 1999). Such financing was arguably more effective for launching these industries than direct financial support to industry R&D.

OECD countries differ considerably in the way they distribute public R&D funds across the various types of R&D-performing institutions (industry, universities, government labs). In 2001, three-quarters of public R&D funds in OECD countries were used to support public research institutes (universities, government laboratories); just one-quarter went to private for-profit and non-profit organisations (Figure 3.9).[27] The United States is atypical in that it allocated almost 40% of government R&D funding to private sector organisations, with more than 30% going to businesses. Only in Belgium, the Czech Republic,

Figure 3.9. **Government R&D funding by sector of performance, 2000**[1]



Note: Nearest available year. 1993 for Austria; 1996 for Italy; 1997 for Ireland, Mexico, New Zealand; 1998 for Australia; 1999 for Belgium, Denmark, France, Greece, Iceland, the Netherlands, Norway, Portugal, Sweden, Turkey, the European Union, and total OECD; 2000 for the Czech Republic, Finland, Hungary, Japan, Korea, Poland, the Slovak Republic, Spain, Switzerland, the United Kingdom and the United States.

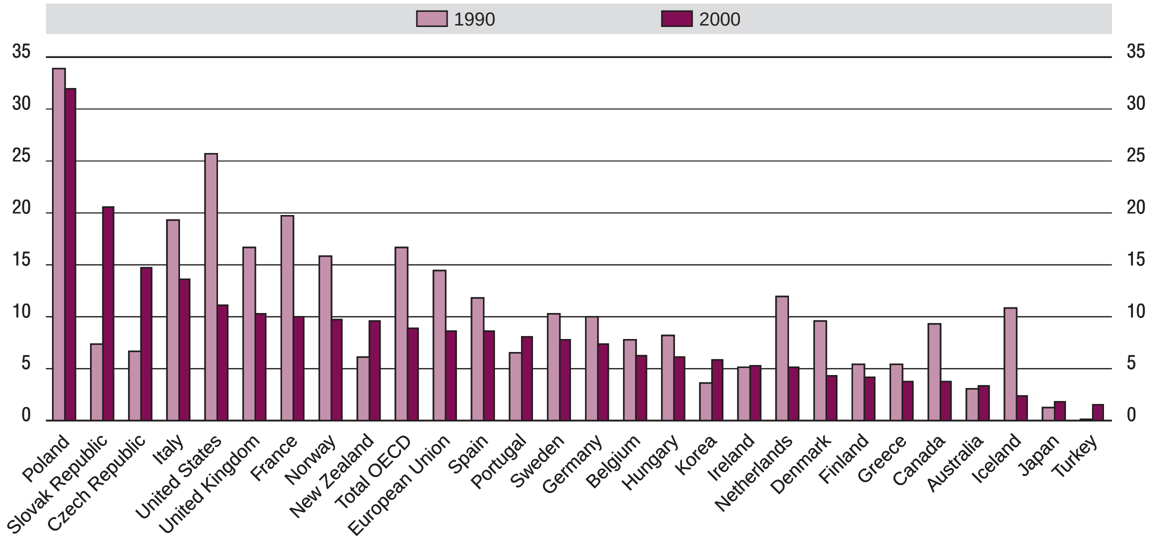
Source: OECD, *S&T databases*, November 2001.

Korea, Sweden and the United Kingdom do more than 20% of government funds go to industry, and in none of these countries does the figure exceed 25%.

Decisions about allocating funding will need to reflect an overall reassessment of the appropriate balance between government support of business R&D (whether through direct funding or tax incentives) and support for knowledge creation. Recent OECD analysis indicates that the effect of public research is greater in countries with higher levels of R&D intensity in the business sector. Hence, countries with lower levels of business R&D may need to place relatively more emphasis on attempts to boost business R&D before boosting spending on public R&D. Where business R&D has already grown and become more efficient owing to greater sharing of knowledge, the business sector is better able to capitalise on new knowledge. The breakdown of closed, proprietary research programmes and the growth of more open exchanges of knowledge have resulted in a more efficient R&D system that is better able to harness knowledge and convert it into new products, processes and services. This can increase the efficiency with which new knowledge developed with public funding is exploited and argues for a shift in government R&D funding away from direct support of business R&D and towards support of knowledge creation. In this case, government can play a stronger role in encouraging the creation of knowledge.

In OECD countries, a notable shift has already occurred in the distribution of government R&D funds between public and private sector organisations. Between 1985 and 2001, the average share of public R&D funds allocated to the business sector declined from 35% to 20%, while public R&D funds to the higher education sector increased from 30% to 40% (the share to government laboratories grew slightly). The fact that this change occurred without a significant increase in overall government R&D spending indicates that government funding has indeed shifted from industry to higher education. In most OECD countries, the share of business R&D financed by government declined significantly between 1990 and 2000 (Figure 3.10). The decline was most pronounced in countries with high levels of government funding at the start of the decade.

Figure 3.10. **Share of BERD financed by government**
Percentage



Source: OECD, MSTI database, June 2002.

Increasing benefits from mission-oriented R&D

Governments can also take steps to ensure greater economic returns on their investments in R&D for missions other than economic growth (*e.g.* national security, health, environmental protection, transportation, space exploration). Such R&D can have significant effects on the development of commercial products, processes and services if: *i*) inventions developed for a given mission can be adapted to commercial applications with little or no modification (this is often referred to as the spin-off model of innovation or as dual-use technology); *ii*) new knowledge that is generated for a particular mission can have applications beyond those missions; or *iii*) the R&D can help reduce other barriers to innovation, such as a lack of reliable standards or market uncertainty regarding the safety of certain kinds of products (*e.g.* genetically modified foods).

In France, Spain, the United Kingdom and the United States, over one-quarter of total government R&D is allocated to defence but can have relevance for the commercial sector (*e.g.* aerospace, electronics, information technology). In Canada, health-related R&D accounts for 25% of the government's R&D budget, and the links between this work and biotechnology are significant. Transportation R&D, whether related to air, sea, road or rail transport, can also fuel economic development through the direct contributions of these services to the economy and their indirect effects on other industries. The strength of the US biotechnology sector no doubt derives in part from health-related research sponsored by the National Institutes of Health. Similarly, advances in information technology benefited from research financed largely by the US Department of Defense (Computer Science and Telecommunications Board, 1999).[28]

Mission-related R&D expenditures avoid much of the criticism levied against direct government financing of business innovation because they serve what are widely considered legitimate functions of government. In addition, government policy makers and R&D managers are generally more capable of determining the R&D needs of their missions than those of industry. Identifying productive areas of work for mission-oriented R&D, while complicated, does not require evaluating or predicting the commercial potential of particular innovations. At the same time, there is no guarantee that commercial benefits will accrue from mission-oriented R&D. In many cases, the technologies developed will have few commercial applications. In others, the technology may serve multiple purposes, but proper linkages between the commercial and government sectors are not in place to facilitate the transfer of technology or knowledge.

Governments can take steps to enhance opportunities for cross-fertilisation between mission-oriented research and economic performance. For example, they can implement policies and programmes (*e.g.* licensing programmes, technology transfer agreements) to support the commercialisation of government technology. They can also try to direct mission-oriented R&D as much as possible towards more basic research that will lead to the creation of generic technologies rather than dedicated products with a narrow set of applications. This may not be possible in cases where a particular product is needed for a government mission, but there may be opportunities to go beyond specific government needs to find more generic solutions.

Encouraging diversity through SMEs

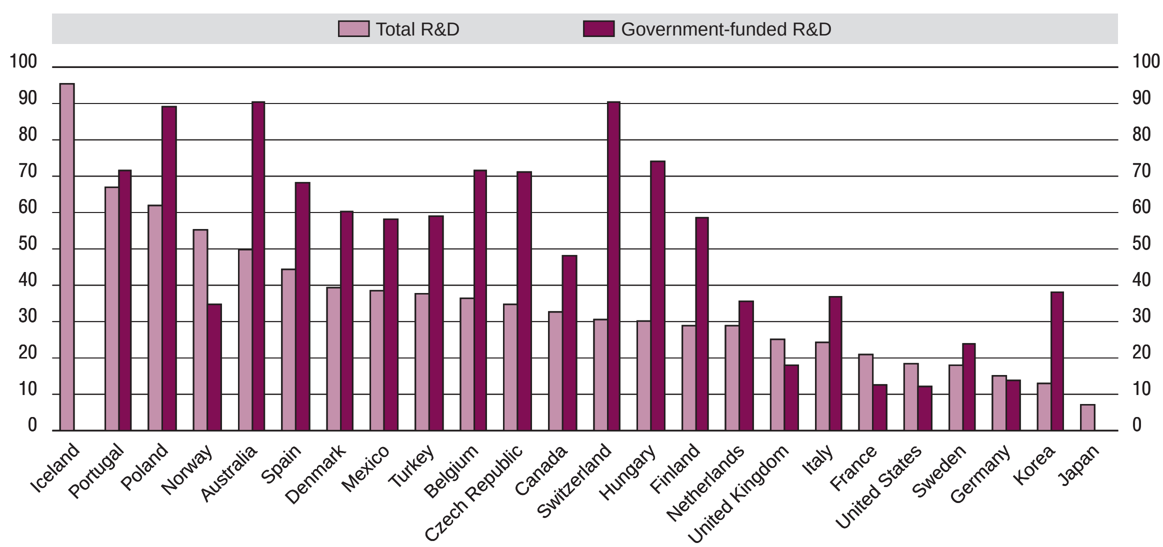
The increased importance of SMEs – particularly new technology-based firms – also has implications for government policy. The interplay between science and technology encourages policies that stimulate experimentation by firms and increase the recombination of new and existing ideas. Policy must encourage companies to conduct experiments, take risks and attempt new combinations of knowledge. This suggests that instead of targeting specific firms to serve as the engines of innovation, government policy may do better to support many smaller firms that develop particular scientific competencies and become attractive investment targets. Policy should also actively seek to incorporate participation from start-ups and other SMEs in research. It should also ensure that they have access to the results of publicly funded research.

Many OECD countries already have government programmes to support SMEs. Some provide general support, but a number focus specifically on R&D. Belgium, Canada, Italy, Japan, Korea, the Netherlands and the United Kingdom offer special R&D tax incentives to small firms. The US Small Business Innovative Research (SBIR) programme requires federal agencies with R&D budgets of more than USD 100 million a year to set aside 2.5% of their R&D budgets for competitively selected awards to small firms.[29] Canada's Industrial Research Assistance Program and the Technology Partnerships Canada offer SMEs technical and seed financing to help stimulate commercialisation of research. Other countries, such as Germany, support private venture capital investment with the aim of aiding new R&D-intensive firms. These programmes are typically justified not only by the additional social and economic benefits that SMEs produce, but also by the particular challenges these firms face – or are believed to face – in the marketplace: difficulty in raising capital for R&D investments, lack of complementary assets to commercialise innovation, limited intellectual property protection to appropriate the benefits of their innovations (Teece, 1987; Anton and Yao, 1994) and difficulties for winning government R&D awards.

Nevertheless, the situation facing new technology-based firms is changing. The expansion of venture capital in many OECD countries has provided a new source of financing for many new technology-based firms. Furthermore, in most OECD countries, the share of government-funded R&D received by SMEs is larger than their share of R&D performance (Figure 3.11). Only in some of the larger OECD countries whose economies are dominated by large firms do SMEs perform a smaller share of government-funded R&D than total R&D. While the relative success of SMEs in winning government funding can be seen as a successful outcome of government programmes, it may also imply that the barriers to their effective participation in government programmes are lower than is thought.

In response to this situation, governments can take a number of steps. First, they can attempt to expand venture capital markets as a means of further encouraging R&D by small businesses. This may take the form of regulatory changes that facilitate the flow of investment money into venture funds (*i.e.* removing restrictions on the ability of pension funds to invest in venture funds) or the use of

Figure 3.11. **SMEs' share of national R&D performance**[1]



1. Most recent available year.
Source: OECD R&D database, June 2002.

government funds to supplement or insure venture capital investments. Second, they can take steps to ensure that their R&D support programmes for small businesses better complement private-sector investments. Private venture capital tends to flow to companies that have the potential to generate high private returns. Most private venture funding has gone to firms in the ICT and biotechnology sectors, suggesting that firms in other sectors continue to have difficulty securing early-stage financing for their businesses and that government support should be directed to them. Recent research indicates, however, that the concentration of venture capital in a particular set of industry sectors is driven more by issues of appropriability than capital market imperfections and that the most successful subsidised small-business projects are in industry sectors with high rates of private investment (Gans and Stern, 2000). Such findings imply that governments should not necessarily support fields with limited private sector funding, but need to ensure that small firms have exhausted opportunities for private support before considering them for public support.

A broader range of policy initiatives could help to stimulate the creation of small firms by facilitating entrepreneurship. Promoting the development of effective capital markets for the formation of start-up firms and for supporting the growth of SMEs is an important step in this respect. This raises issues relating to bankruptcy law and the extent of personal liability, the ability to issue stock to investors and employees, treatment of stock options (*e.g.* when these are taxable), the treatment of capital gains on equity investments, regulatory requirements for listing stock on public exchanges and the depth and rigor of financial reporting requirements. Other issues include international differences in the treatment of stock options and ways to account for intangible assets (*e.g.* investments in intellectual property, R&D, worker training) on corporate balance sheets, much as goodwill is included today.

Responding to globalisation

Globalisation of R&D raises many issues for policy makers and business executives. Countries hoping to use foreign direct investment to boost employment, economic output and R&D spillovers continue to seek ways to attract investment, for example through tax incentives or an educated workforce. Countries that are already highly internationalised (*e.g.* smaller northern European countries) are more interested in reinforcing innovative strengths and maintaining their niche in the global environment. Large, technologically advanced countries tend to be more concerned about minimising the leakage of technology abroad while remaining attractive bases for industrial research. As small firms become more tightly integrated into global innovation networks and global markets, they find they must develop the capacity to accommodate different markets and regulatory bodies.

While concerns will persist regarding the leakage of domestic technology and the take-over of a country's R&D performers by foreign-owned firms, policy makers need to take a positive view of emerging patterns of globalisation. Globalisation of R&D diminishes economic autarky, boosts economic interdependence among nations and brings new technological capabilities to a region. Much of the technology developed in foreign-owned labs is exploited in local markets, and some firms allow foreign research labs to pursue R&D to meet local market needs and to deploy research results first in local products.[30] Perhaps more importantly, the new motivation for globalising R&D – to tap into local centres of expertise – provides a significant opportunity for smaller economies to enter emerging industry sectors and to tap into global markets. Individual firms and research organisations with world-class capabilities can easily enter the global value chains of knowledge production and application, attracting investment from abroad and contributing to the open innovation systems of larger firms. These organisations can serve to encourage the development of domestic industries.

Responding to emerging technological opportunities while balancing market forces

The increasing reliance of national innovation systems on business-funded R&D heightens their sensitivity to market forces, which can greatly affect both overall levels of R&D funding and their distribution across industry sectors and research disciplines. Increases in venture capital financing combined with increased use by large firms of M&As and CVC to acquire knowledge during the late 1990s made business R&D more sensitive to stock market fluctuations. As market values of firms declined, venture capital firms curtailed new investments and large firms were unable to use their stock price to acquire other firms, slowing both the creation and transfer of knowledge. At the same time, tremendous growth in business R&D in the ICT and biotechnology sectors in many countries shifted overall R&D portfolios towards these industries and their supporting academic disciplines (computer science, electrical engineering, life sciences).

In this environment, governments must determine how government R&D funding can best complement industry's investments to ensure that suitable levels of knowledge creation feed growing industries while ensuring balance across R&D portfolios. Governments may also have a role in acting counter-cyclically to compensate for economic downturns that might stifle business investments in R&D and to help R&D-conducting organisations in the public and private sectors maintain their R&D capabilities for future use.[31] At the same time, governments need to ensure that they do not contribute to the creation of bubble economies by amplifying business and investment cycles.

Moreover, governments will need to establish processes for evaluating the balance of their own R&D investment portfolios, as they will be increasingly called upon to support areas of emerging business interest. While a rise in business R&D investment in a certain area may be interpreted as meaning that government support is less necessary, there are strong arguments in favour of shifting government R&D financing towards areas of growing business interest. Growing business R&D investments imply that industry will be better able to capitalise on new knowledge and incorporate it into new products, processes and services. The concern with such an approach is that unless government R&D budgets expand commensurately, increases in government funding for some fields must come at the expense of others. Arguably, such decreases reflect a shift from areas with lower social returns to those with higher returns, but this is difficult to judge, leaving policy makers with few good tools for sound decision making (Cohen and Noll, 2001). Furthermore, diversity in R&D portfolios is needed to allow for the serendipitous discoveries that may be important for spawning new technological breakthroughs and, possibly, new industries. In general, government is better able than industry to support diversity, but processes must be put in place to ensure that the proper balance is struck.

Ensuring linkages among innovating organisations

Emerging patterns of business R&D further emphasise the importance of strong linkages between R&D-performing organisations in the public and private sectors.[32] The shift to more open innovation systems in the private sector is predicated on firms' ability to identify and acquire externally produced scientific and technical knowledge, whether in other firms or in universities or government laboratories. Conversely, the open model of innovation relies on the ability of public- and private-sector organisations to market technologies that they cannot fully utilise internally.

The transition from closed to open innovation is one that firms must largely make themselves by reorganising their internal R&D activities and recognising the importance of external linkages. Nevertheless, government policy can play an important role in facilitating this transition by removing potential barriers to an open innovation system and by encouraging its formation. Many of the steps outlined above can contribute: stimulating diversity through new technology-based firms; encouraging knowledge creation through financing of public-sector research and support of basic research; and employing instruments for financing business R&D, such as tax credits, that can support a large number of firms in diverse industry sectors. Some policies may need to be re-evaluated, such as those affecting collaborative research, mergers and acquisitions, mobility of human resources and intellectual property rights. Specific policy measures may also be put in place to encourage networking between firms and stronger linkages among industry, universities and public research organisations (OECD, 2002b). Such policies exert significant influence on the openness of innovation systems and need to be explicitly considered in formulating innovation policies.

Intellectual property rights

As a result of the increased exchange of technology among firms, universities and government labs, formerly technical issues such as protection of intellectual property have taken on greater importance for government policy making. IPRs have become an important mechanism for diffusing technology as firms seek to acquire technology developed by other R&D organisations and make a business of licensing their own IP (although the sums concerned are still small compared with mainstream business activities). Because patents cannot fully describe a technology and its implementation, such licensing often entails continued co-operation between and among firms. Policy makers must remain concerned with the trade-off between protecting rights to inventions and encouraging their diffusion, but recent shifts in firms' R&D strategies suggest that markets may play a more important role in promoting diffusion than in the past. As companies look to profit from the use of their IP outside their own businesses, the supply of knowledge available in the market is likely to increase. Governments should therefore clarify the ownership of IP and provide the institutional and legal support for its purchase and exchange.

A further and more nettlesome issue is whether and how governments should assign IPRs to the results of research that it funds itself. In the United States, for example, the Bayh-Dole Act of 1980 allows universities that conduct research with government funds to file for patents on results of that research, the patents to be owned by the university. The results, and related legislation, are hotly debated but are very important. If industry is to rely increasingly on government and especially university research for new knowledge, such issues become critical policy levers that can enable or thwart advances in a country's innovation system. Effective solutions will require careful crafting of policy to ensure that scientific and technical advances can be brought to the marketplace without unduly limiting their diffusion or influencing the nature of public research.

Summing up

As the above discussion implies, governments will continue to have an important role in supporting business R&D, despite recent increases in business R&D expenditures. The public sector appears to have a growing role in creating the basic scientific and technical knowledge that firms then incorporate into new products, processes and services. As the business innovation system becomes more diffuse, government policies will have to respond accordingly, helping to create an environment in which innovative activity can flourish and knowledge can be easily exchanged. In doing so, governments will need to:

- Strengthen support for basic research.
- Make decisions regarding the financing of business R&D in the context of support to R&D in universities and other public research organisations.
- Strike a balance between direct financing of business R&D and tax incentives for R&D to ensure that government programmes are well matched to the impediments firms face for investing their own funds in R&D.
- Ensure a fertile environment and availability of financing for SMEs, particularly start-up firms, in the context of growing venture capital investments.
- Structure mission-oriented R&D so as to increase opportunities for spillovers and spin-offs to commercial innovation.
- Establish mechanisms for responding to emerging scientific and technological opportunities while maintaining balance in funding portfolio across fields and disciplines.
- Ensure strong linkages among innovating organisations in the public and private sectors.
- Revisit existing regulations governing the protection of intellectual property and licensing to facilitate diffusion of knowledge while providing firms with incentives to invest in innovation.

An as-yet-unanswered question is how to build and sustain political support for government S&T and innovation programmes, especially as they shift from supporting individual firms to creating an environment that is conducive to innovation. A key virtue of direct incentives is that the beneficiaries know who they are and can mobilise support for incentive-based policies. Many of the policies noted above are far more indirect, and most ultimate beneficiaries are harder to identify specifically. New metrics for measuring outcomes and assessing policy will be needed. Without a clear understanding of industry practices, governments are likely to measure the wrong outcomes, causing their evaluation of policy initiatives to be surprising and disappointing. This in turn would make it harder to improve policy and to gain support for new policy. With better appreciation of the changes in business R&D strategies, however, governments can develop and implement effective policies for boosting business R&D and channelling it to economic and societal needs.

NOTES

1. These might include difficulty in appropriating the returns from R&D or in securing financing for R&D, or overwhelming technological risks.
2. Systemic failures might include a lack of sufficient venture capital to finance start-up firms, lack of co-operation between universities and industry or limited mobility of human resources.
3. Such R&D is financed largely with industry funds, but also with contributions from government and other national sources.
4. In the European Union and the United States, government R&D funding was lower in 2000 than in 1990, despite slight increases in the late 1990s. This trend reflects both a reduction in defence-related expenditures and fiscal restraint in the United States and several large European economies.
5. The effect has been especially pronounced in the United States, where industry-funded R&D surged in the late 1990s and accounted for 68% of GERD in 2000, up from 55% in 1990. European Union countries have seen a similar pattern, with the government's share of R&D funding declining from 41% to 35% as industry's share rose from 52% to 56%. In Japan, where government funding has historically been low and industry investments in R&D have been constrained by other economic factors, the government's contribution to R&D grew slightly between 1990 and 2000, from 18% to 20%. As a whole, however, national governments now play a smaller role relative to industry in supporting R&D.
6. As a result of this significant increase, ICT grew from 26% to 38% of total business expenditures on R&D in the United States between 1990 and 1998.
7. France also shows an interesting growth pattern, with a significant shift away from other manufacturing industries (driven almost exclusively by steep reductions in R&D in the aerospace industries) and towards ICT, pharmaceuticals and services, but aggregate growth in BERD amounted to only 15% between 1990 and 1999. Australia also presents an interesting case, because it experienced significant growth in R&D – and significant growth in GDP and multifactor productivity (OECD, 2000a) – but almost 60% of the growth in BERD was in other manufacturing industries and in non-manufacturing areas other than services.
8. Data from the National Venture Capital Association. See *www.nvca.com*. Interestingly, considerable venture capital funding in the United States comes from pension funds financed by large corporations.
9. Data from the European Venture Capital Association. See *www.evca.com*
10. New generations of disk drive technology were consistently introduced by new firms, in part because customers of existing firms saw little advantage in smaller size when it implied accepting lower storage capacity. Over time, the storage capacity of the new devices exceeded that of the older technology.
11. Consistent with this statement, relational database technology and reduced instruction set computing (RISC), for example, were both invented in large corporate laboratories but brought to market by start-up firms, in part because of concerns about cannibalising existing product lines in the large firms (Computer Science and Telecommunications Board, 1999). Biotechnology was also pursued more vigorously by small start-up firms than by entrenched competitors in pharmaceuticals and agrifood businesses (see Christenson, 1997; Robbins-Roth, 2000).
12. One of the most famous examples is that of Xerox Corporation, whose Palo Alto Research Center developed many of the basic technologies of personal computing, yet failed to introduce a successful personal computer (Smith and Alexander, 1988; Chesbrough, 2002a). The difficulty firms face in fully appropriating the benefits of R&D (and preventing competitors from capturing some of the benefits) has been thoroughly explored in the economics and business literature and forms a primary justification for government support of business R&D.
13. Companies undertaking internal research have other reasons beyond these beliefs. Mowery (1983) provides a sustained and well-supported argument that the ability of firms to co-ordinate complex and tacit information caused the locus of research to shift from the outside to within the firm. The mobility of labour and the rise of start-up firms are causing the locus of research to shift once again.
14. For example, Xerox Corp. announced that it would spin off its Palo Alto Research Center (PARC) as an independent organisation in early 2002. PARC is legendary for having created many of the technologies that are commonplace in personal and office computing, but Xerox was unable to capitalise on its output. Similarly,

Interval Research Corporation, a well-funded, unaffiliated industry research lab, closed its doors in late 2000 owing, in part, to an inability to commercialise its results. Several other incubators have faced a similar fate.

15. On the basis of data from the OECD ANBERD database and from the National Science Foundation (2000).

16. For a more complete discussion of industry-science relations and relevant indicators, see OECD (2002a).

17. Data from *The Corporate Venturing Report* as cited in Silverman (2000). Cited figures do not include companies that take minority equity stakes in start-up firms on an *ad hoc* basis.

18. CVC funds are not limited to US firms. A number of European and Japanese companies, including Alcatel, France Telecom, Hitachi, Novartis, Philips, Siemens and GlaxoSmithKlineBeecham, have CVC funds.

19. Intel Corp. operates one of the largest venture funds in Silicon Valley, with USD 5.9 billion of equity invested in domestic and international firms that develop Internet infrastructure, content and services. Lucent Technology's venture arm, Lucent Venture Partners, created two venture funds totalling USD 250 million that invest in early-stage technology companies in high-growth communications areas such as optical, data and wireless networking, semiconductors, communications software, professional services and e-commerce. Daimler-Chrysler created a venture fund to invest in ICT that could be applied to automotive products, and both Kodak and Qualcomm announced new venture funds totalling USD 100 million and USD 500 million, respectively, at the end of 2000.

20. Data from Cisco System Inc. annual reports.

21. A summary of this workshop, co-sponsored by the OECD, the European Industrial Research Management Association and the French Ministry of Research, is available on line at *www.oecd.org/sti/innovation*

22. It should be noted that data on R&D funding from abroad are difficult for countries to report and are subject to changing definitions over time. Time series data and international comparisons must therefore be interpreted with caution.

23. Of course, not all government R&D investments should be made in pursuit of economic objectives, but to the extent that economic growth becomes a primary motivation for public R&D expenditures, some changes will undoubtedly be necessary.

24. These data use the definition of basic research outlined in the 1993 *Frascati Manual*, which defines basic research as "experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts without any particular application or use in view". The results of basic research are not generally sold but published in scientific journals. The research may be oriented towards some broad fields of general interest, forming the background to the solution of current or future problems.

25. The financial value to firms of tax credit programmes is strongly influenced by overall corporate tax rates and by the structure of R&D tax incentives, including: whether the tax credit is applied to total R&D expenditures or just to incremental increases over a certain base, the fraction of qualifying R&D expenditures that can be excluded from income or credited against tax liabilities. For a more detailed discussion of tax incentives, see OECD (1998a), Chapter 7.

26. These sectors correspond to four North American Industrial Classification System codes: 3345 (navigational, measuring, electromedical and control instruments); 3364 (aerospace products and parts); 5413 (architectural, engineering and related services); and 5417 (scientific R&D services).

27. These figures mask considerable variation: the percentage of public R&D funds allocated to universities ranges from 22% in Korea to over 80% in Turkey, with the OECD average hovering around 40%.

28. As recently as 1995, 70% of university research in computer science and 65% of university research in electrical engineering was supported by the federal government; over half of this funding came from the US Department of Defense.

29. Part of the selection criteria for such awards is a demonstrated ability to obtain private-sector support for subsequent commercialisation of innovations.

30. This is true of Canon and its research centre in Rennes, France, for example.

31. Evidence from the Spanish electronics industry suggests that during economic downturns, business R&D becomes more dependent on public funding so that research positions in universities and public research organisations become more attractive. See the study made available by Paloma Sanchez of the Autonomous University of Madrid and Jesús Banegas of the Asociación Nacional de Industrias Electrónicas y de Telecomunicaciones (ANIEL) to the Workshop on Changing Business Strategies for R&D and their Implications for S&T Policy, Paris, October 2001. Available at: *www.oecd.org/sti/innovation*

32. The importance of such linkages is also highlighted in recent work on national innovation systems. See OECD (2002b).

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